Docket: FG - 21

TITLE: OPTICAL FIBER ARRAY ASSEMBLY AND METHOD OF MAKING

RELATED APPLICATION: U.S.Provisional Patent Application SN.60/421,032, filed October 24, 2002.

BACKGROUND:

The present invention relates to optical fiber arrays and more particularly to new array designs and methods of making the same.

It is commonly known in the art that there is a need for large, high-density optical fiber array apparatus used to connect or otherwise employ large numbers of optical fibers in transmission and switching systems. Although advances have recently been made in achieving high density arrays with the use of thin silicon or other etchable material front masks and photolithography techniques to

form the high-density holes various related problems remain to be solved. Some of the problems result from the use of bonding materials (e.g. epoxy) to hold together the front mask and additional plates or masks. These plates or masks function as reinforcing plates, guide masks, fiber alignment masks, and housing-mask spacers, as desired. Applicants have found that the bonding materials tend to crack or separate in the field and moisture can collect in the tiny resulting spaces which, upon freezing, cause major cracks, separation, and problems, which shorten the life cycle or field life of the overall apparatus. Another resulting problem in high-density arrays is that the epoxy absorbs moisture which can adversely effect the critical flat-ness of the assembly front mask.

An object of the present invention is to solve these problems and provide other benefits in the design and construction of optical fiber arrays, connectors, and apparatus and methods of making the same.

SUMMARY OF EXEMPLARY EMBODIMENT OF THE INVENTION:

The present invention includes an optical fiber array that includes mask assembly having a front mask made of etch able material, e.g. silicon, which is aligned with and permanently bonded, without the use of epoxy or other standard bonding

material, to an etchable, e.g. silicon, guide mask. The silicon front and guide masks are, according to the principles of the present invention anodicly bonded to opposite sides of a glass bonding die which has the same or significantly similar coefficient of expansion as the front mask. In this way, the front mask bonding die, and other mask elements act as a single unit with substantially the same thermal expansion and contraction parameters. In addition, the bonding mechanism is permanent and does not absorb moisture that would cause separation of the masks and plates.

In one exemplary embodiment, the wafer is made of silicon and the bonding die can be made of any suitable high temperature resistant glass and the two elements are bonded together by anodic bonding techniques.

In another embodiment, silicon front and guide masks are bonded to an intermediate glass bonding die. The bonding die can be made of 7740 Pyrex (a registered trademark of Corning Glass, Inc.), or Borofloat (a registered trademark of JENAer Glaswerkeg NbH) or other suitable high temperature resistant glass.

In yet a further embodiment, the silicon guide mask of the three element wafer pack is further anodicly bonded to a glass spacer that functions to strengthen the pack against polishing forces and provide a mounting platform to the array housing. The

spacer material can be the same as the bonding die material and its thickness dimension predetermined to precisely position the front mask surface relative to the housing or other optional elements that interact with the fiber ends held in the front mask.

Anodic bonding is a known process for joining glass elements to various materials having a similar structure. Conventional apparatus includes a hot plate for heating the assembly, an anode for providing a positively charged electrode source such as an electrolytic cell, storage battery, or electron tube, and a cathode or negatively charged element from, such as, an electrolytic cell, storage battery, or electron tube. A mounting fixture with some means for supporting and aligning the elements to be bonded is also used. Controllers provide power, polarity, timing, etc. to control the process.

For greater detail of anodic bonding, see (1) SELECTION OF GLASS, ANODIC BONDING CONDITIONS AND MATERIAL COMPATIBILITY FOR SILICON-GLASS CAPACITIVE SENSORS, by T. Rogers, J. Kowal, Sensors and Actuators, A 46-47 (1995) 113-120; (2) http://mems.eeap,cwru.edu/shortcourse/partI 2.html, section 2.3.1; (3) SILICON WAFER BONDING: KEY TO MEMS HIGH-VOLUME MANUFACTURING, A.R. Mirza, A.A. Ayon, Sensors Magazine, Dec. 1998.

In one present process example, the hole matrixes of the stacked front silicon mask and glass element bonding die are

aligned. The process elevates the silicon mask/bonding die package temperature and bonds silicon to Pyrex by applying a negative potential to the Pyrex element which creates a standing electric field across the elements interfaces. Sodium positive ions in the glass bonding die are driven to the cathode to create a space charge at the Pyrex silicon interface. This space charge produces strong electrostatic forces between the silicon wafer and Pyrex bonding die that holds both pieces together. Oxygen ions from the Pyrex simultaneously transfer to the interface of glass and silicon to form a thin silicon dioxide film, which creates a permanent bond at the interface. No film is formed across the aligned array holes of these parts. Although anodic bonding process is generally known, its application to optical fiber front and guide, plate bonding is believed to be novel because of the technical problems solved and new benefits provided by application of this process to the manufacture and performance of high density optical fiber arrays.

A further exemplary embodiment of the present invention includes forming a wafer pack that includes a silicon front mask wafer, a glass bonding die made of high thermal resistant glass, a silicon guide mask, and, optionally, a glass spacer stacked in that order. These elements are anodicly bonded together into a wafer pack so that they are permanently bonded without application of

epoxy or equivalent materials. In order to bond the silicon guide mask to the bonding die, the bonding field polarity is reversed so that the previous anode/cathode becomes the cathode/anode in function. In this way the bond between the front mask and bonding die is unaffected and the bond between the bonding die and guide mask is formed in the same manner described above.

If a spacer is desired the present invention includes positioning the glass spacer to the rear of the silicon guide mask and anodicly bonding these parts, again by reversing the polarity to the bonding field. The other bonds in the stack are unaffected by the spacer-guide mask bonding process.

Yet a further object of the present invention is to provide a new mask assembly of the type described that includes a silicon front mask, glass bonding die, silicon guide mask, and glass spacer in that order, and each adjoining surface of each element being bonded to the adjacent surface by a layer of oxide material formed by migrated ions of the glass elements respectively.

A still further object is to provide a silicon front mask anodicly bonded to a glass lens array element.

DESCRIPTION OF THE DRAWINGS:

Other further objects, benefits and advantages will become apparent with the following detailed description of exemplary

embodiments of the present invention when taken in view of appended drawings, in which:

Figure **1** is an exploded perspective elevation view of one example of wafer pack elements to be stacked and bonded in accordance with the principles of the present invention.

Figure **2** is a schematic and pictorial view of the apparatus that can be used to form the bonded wafer pack and process according to the principles of the present invention.

Figure **3** is an exploded, partial vertical section of the wafer pack of Figure **1** after it is anodicly bonded.

Figure **4** is similar to Figure **3** showing an alternate embodiment of bonded plates, according to the present invention.

Figure **5** is yet another alternate embodiment of the present invention including a silicon front mask and a glass lens element.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS OF PRESENT INVENTION

With reference to Figures **1** - **3**, one example of a wafer pack **10** according to the principles of the present invention include a high density front mask wafer **12** having an array of precisely positioned and dimensioned holes **22**, a bonding die plate **14** having corresponding holes **24**, a guide or second wafer **16** having corresponding holes **26**, and a high thermal resistance glass plate

18 having corresponding holes **28**. Plate **18** can function as a spacer by selecting its thickness to precisely position the front surface of wafer **12**. Also, plate **18** can function as a support plate to reinforce the other elements during polishing and grinding wafer **12** front surface. Each of these elements includes suitable means to precisely align each element with the others so that all respective array holes **22** - **28** become precisely aligned along common hole axes **38**. See Figure **3**. One example of such means is shown in Figures **1** and **2** as alignment holes **20** that cooperate with alignment pins **21**, further described below.

In a preferred embodiment wafers **12** and **16** includes thin, etchable material, such as **125**micron thick silicon. Wafer **12** is intended to function as a front mask for an optical fiber connector or other optical device having 8 x 8, 19 x 19 or higher array holes. Second wafer **16** can also be made as a thin plate and function as a guide mask to guide the insertion and penetration in the front mask of the front cladded core portions of individual optical fibers, such as **35**, Figure **3**. Wafer **16**, too, can be made of silicon or other suitable etchable material. Holes **22** can have straight cylindrical sidewalls as shown or be flared as desired to assist in fiber tip insertion. Holes **26** can be cylindrical toward the surface facing mask **12** and flared outward toward the back-side

of wafer **16**, as shown, or can be cylindrical or conical throughout as desired.

Bonding die **24** is preferably made of high thermal resistant glass and serve as a spacing, reinforcing or strength element to wafers **12**, **16**. Holes **24** can be shaped to guide inserted fibers or can be larger as shown so that bonding die simply functions as a spacer and/or strength element. Glass spacer **18** provides reinforcement to the finished wafer pack and serves as a mounting element at or near the front zone of a metal or plastic housing **11**, Figure **3**. Holes in plates **14**, **18** can be formed by ultrasonic milling or other suitable method.

Examples of the types of housings, masks, hole designs, apparatus, assembly methods, parts designs, features, and functions are described in more detail in U.S. Patent No. 5,907,650 and U.S. Patent applications 09/841,686 and Publication WO 01/94995 A2 all incorporated herein by reference.

An exemplary anodic bonding apparatus **30** suitable to carry out the present method includes a hot plate apparatus **32**, a temperature sensor (thermocouple) **36**, voltage/controller **38** to apply, control and indicate anode/cathode voltage, and electric power source **40** and one or more electrodes **34** function to apply voltage fields more fully described below. Preferably, surface of hot plate **32** is grounded and functions as a system electrode. Also, alignment pins

21 cooperate with alignment holes **20** as described above to align the array holes of elements **12, 14,** and **16**. Pins **21** can be made of stainless steel, ceramic, glass, or other suitable material. Additional glass pins or cut pieces of fiber (not shown) can insert through array holes (preferably located at the array corners) and can have the same diameter as the fiber diameter to align the array holes more accurately than with the use of larger pins **21** alone or instead of using pins **21**. Plate **23** can be 1/4 to 1/2 inch thick and made of low expansion metal, such as 416 steel, COVAR or INVAR preferably lapped and polished to a very flat surface and finish on both sides. Devices such as gauged switches **25, 27** provide voltage polarity reversal between anode and cathode.

An exemplary method of forming a wafer pack will now be described with reference to Figures **1, 2** and **3**. Typically, element thicknesses are silicon wafers 500 - 650 µm, bonding die 250 µm, spacer .125 inches.

<u>Prepare Pieces</u>

- Provide etched silicon wafers **12, 16**.
- Provide a high thermal resistant glass (e.g. Corning 7740 Pyrex) spacer **18** and bonding die **14**.
- Clean all parts per Corning 7740 glass specifications except for HF section.

Prepare for Bonding

Stack plates **12, 14,** and **16** in order shown in Figure **1** on pins **21** with wafer **12** front face facing away from die **14.**

- Place stack on mounting die **23** with front face of plate 12 contacting mounting die **23.**
- Place mounting die **23** on hot plate **32**

Bonding

- Ramp up hot plate **32** surface temperature to between 300°-450° C.
- Then turn on (apply) voltage supply to within range of 1000V - 1200V and hold for 8 to 12 minutes, preferably 10 minutes.
- Reverse voltage polarity and hold for about four minutes.
- Thereafter, turn off hot plate **32** but leave on voltage **40** for an additional 5 - 20 minutes.
- Thereafter, allow plate to cool to 100° C, then remove bonded wafer pack.

To Bond Spacer **18** Element

- Pre-clean spacer **18**
- Mount spacer **18** on pins **21** (and/or on additional pins) so its front surface contacts the back surface of wafer **16.**
- Place or leave mounting die **23** and wafer pack **10** on hot plate. Ramp up hot plate temperature to 300° - 450°C.

- Reverse (i.e. change to original polarity) and apply voltage **40** to within range of 1000V - 1200V for about 8 to 12 minutes, preferably 10 minutes.
- Turn off hot plate but leave voltage **40** on for an additional 5 - 20 minutes.

As seen in Figure **3** sodium ion and oxide layers **13, 15, 17** have formed between wafer **12,** bonding die **14,** wafer **16** and spacer **18,** respectively. The pack **10** is therefore permanently bonded as a unit with array holes **22, 24, 26,** and **28** aligned along the same axes **38** normal to the planes of the wafer and plate or die elements.

An alternate embodiment is shown in Figure **4** in which front mask **12** is bonded anodicly directly to spacer plate **18** by the above-mentioned process except that polarity reversal is not needed for two element bonding. Oxide layer **17** in this case forms at the interface of these two elements.

Yet a further embodiment is shown in Figure **5** in which front mask **12** front surface is bonded anodicly directly to a glass lens element **40** after fibers **35** are seated and secured with standard epoxy application (not shown) and the front mask ground and polished. Lens **40** can be convex or concave as desired. A layer of oxide material forms at the interface of the lens/front **41** mask as

stated above. The dotted line indicates other plates and/or masks could have been bonded as part of the package as desired.

It will be understood the drawings are conceptual and not drawn to scale.

It should be understood that an alternate exemplary method includes forming the initial sub-stack and anodicly bonding wafer **12** to die **14**. After that, wafer 16 is added to the sub-stack and anodicly bonded to die **14**. After that, glass spacer **18** could be added to the stack and then anodicly bonded to wafer **16**. Also, in all applications of the above embodiments, fibers seated in the front mask should be secured therein, e.g. by way of standard epoxy application to the front mask front surface after which the exposed fiber tips, epoxy, and front mask surface can be ground and/or polished as desired. See for example U.S. Patent No. 5,907,650.